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Advancements in Food Microbiology: Exploring Prebiotics, Probiotics and Synbiotics

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ABSTRACT

The growing field of food microbiology encompasses various aspects, including food production, processing, preservation, and storage. This review explores the crucial roles of microbes in these areas, highlighting both their beneficial and detrimental effects. The potential of proteomics for food quality and safety control is discussed, emphasizing its effectiveness in allergen detection and characterization. Furthermore, the review examines the concept of microbiological risk assessment and the evolving strategies for rapid microbial monitoring. It delves into the exciting realm of prebiotics and probiotics, exploring their individual and combined (synbiotic) applications in promoting gut health and managing various health conditions. The review concludes by summarizing the potential of prebiotics and probiotics in functional foods and emphasizing the need for further research to elucidate their mechanisms of action and optimize their health benefits.

INTRODUCTION

A subfield of microbial ecology is food microbiology [1]. The food ecology is made up of extrinsic elements (such as temperature, gaseous environment, and the presence of other microorganisms) and intrinsic factors (such as pH, water activity, and nutrients), which are factors that are external to the food [2]. Pasteur's discovery that yeasts were the cause of alcoholic fermentation established the connection between microbiology and food. The field of food microbiology has attracted increasing attention from the scientific community and industry ever since that discovery. It is astonishing how many food products use fermentation at one or more stages of their manufacturing. They are regarded as one of the food industry's most inventive product categories and are a significant part of the regular diet [3]. Microbiology plays a crucial role in the production, processing, preservation, and storage of food. The manufacture of food and food ingredients, such as wine, beer, bakery goods, and dairy products, uses microbes like bacteria, molds, and yeasts. However, the development and contamination of harmful and spoilage microbes are now thought to be one of the primary reasons for food loss [4]. In addition to the relative financial losses, food safety and quality issues and the risks they bring to consumers' health are a big concern on a global scale. Unsuitable food safety measures may undermine customers' trust in the integrity of the food supply. The food industry's economy and consumer confidence may be negatively impacted by a lack of accurate measurements and assays to assess and maintain excellent control over food quality. Fast and dependable analytical techniques that enable accurate and timely food product analysis throughout the entire food chain must be developed and established. Because of its good quantitative and qualitative record in protein analysis, proteomics can be a potent tool in addressing this problem [5]. It is estimated that up to 4% of people and infants in affluent nations suffer from food allergies, which are hypersensitivity reactions mediated by IgE. Food allergies mostly result from proteins known as allergens, which can cause mild to severe systemic reactions. Proteomics comprises multi-dimensional protein separation and mass spectrometry identification, with bioinformatics tools being used to analyze the data. Proteomics is being used more and more in the field of allergies to: (i) identify the genetic and phenotypic variability of allergens in crops; (ii) obtain well-characterized allergens as reported within the Integrated Project EuroPrevall, funded by the European Commission; and (iii) detect and quantify allergens in complex foods like bread, cookies, and the like, either in their native form or in forms resulting from food processing, as taken into consideration by the MoniQA project [6]. Characterization and quantification of food protein allergens, in conjunction with immunoglobulin E epitope mapping, will aid in the diagnosis and prognosis of food allergies and improve food safety evaluations (e.g., novel transgenic foods) [7]. Foodborne illness remains a substantial burden, with microorganisms playing a major role, despite significant efforts by all parties involved. Microbes are extremely adaptable, allowing them to survive, thrive, and produce harmful substances. They can also enter the food chain at numerous points. Because of this, their study differs from that of food toxicology and chemical agents. Good Manufacturing Practices and Hazard Analysis Critical Control Points (HACCP) are widely recognized concepts that form the foundation of food safety management [8]. The idea that a food's microbiological quality is the outcome of a series of interactions is becoming more widely accepted. The production of raw materials, distribution, and consumer handling are all aspects of overall processing that must be considered to ensure the microbiological safety of food. Consequently, meticulous process chain design is just as important to the microbiological quality assurance of food as control. The food sector is currently applying the HACCP concept and has widely adopted quality assurance methods. These situations call for the deployment of rapid microbiological monitoring technologies. Quick, easy-to-use, and adaptable microbiological tests are required [9]. Methods based on culture and genetics offer distinct perspectives on the characteristics and actions of bacteria. To get the most out of both strategies, you need to be aware of their limitations and use them accordingly. Genomic analysis is excellent at determining the relationships between isolates and identifying microorganisms. Culture-based techniques are still required for enumeration and detection, viability assessment, and validation of phenotype predictions based on genetic analysis bias [10]. In the field of food safety, microbiological risk assessment is a relatively recent profession. Determining the quantity of microorganisms in food at any time that is, measuring an individual's exposure to the microorganism is one of the challenges involved in microbial risk assessment. Food production and processing methods, as well as the type of food being produced, can all affect the number of bacteria present in the final product. One can evaluate an individual's exposure to a pathogen by using predictive microbiology to estimate changes in bacterial counts [11]. A growing multidisciplinary field in food microbiology is called predictive food microbiology (PFM). To create and use mathematical models to forecast how microorganisms will react to particular environmental conditions, it incorporates fields including mathematics, microbiology, engineering, and chemistry [12].

Prebiotics: Nourishing the Gut Microbiome

Prebiotic theory operates under the premise that humans already harbor a multitude of microbes that may be beneficial to their health [13]. There is a great deal of interest in modifying the composition and metabolic activity of the gut microbiota due to its critical role in health. Presumptively fermented nondigestible dietary items or substances that especially support the growth and/or activity of health-promoting bacteria that colonize the gastrointestinal tract are known as prebiotics, and they represent one of these tactics [14]. Prebiotics are non-viable food ingredients that good gut bacteria specifically digest. By increasing the quantity and/or activity of *lactobacilli* and *bifidobacteria* in the diet, prebiotics can modify the gut microbiota and promote better health [15]. In recent years, there has been a growing interest in their connection to human health in general. Their breakdown products, short-chain fatty acids, are released into the bloodstream and can nourish the gut microbiota. This can have an impact on distant organs in addition to the gastrointestinal tracts. The two major classes of prebiotics that are helpful to human health are fructo-oligosaccharides and galacto-oligosaccharides. Scientists are working to create prebiotics on an industrial scale because foods naturally contain small amounts of fructo- and galacto-oligosaccharides. Given the advantages prebiotics have over probiotics in terms of manufacturing and storage, safety, and health benefits, they appear to be intriguing options for enhancing human health either in place of or in addition to probiotics [16]. Numerous bacterial populations are found in the gastrointestinal tract, both on mucosal surfaces and in the gut lumen. In many gastrointestinal illnesses especially in the elderly, there is an imbalance in the populations of bacteria. According to research done thus far, prebiotics and synbiotics can help regulate the gut microbiota. They also show promise as therapeutic agents for colon cancer and inflammatory bowel disease, as well as for preserving the proper balance of microorganisms in the aging gut [17]. Prebiotic carbohydrates will probably be demonstrated to have positive health impacts in the end since they have distinct and important physiological effects on the human large intestine [18]. Many fruits and vegetables include prebiotics, which are regarded as functional food ingredients with major technical benefits. Their presence increases a wide range of food applications, including dairy products and bread, by improving sensory attributes like flavor and texture as well as the stability of foams, emulsions, and mouthfeel [19].

Table 1 Prebiotics in food [20]:-

Prebiotics	**Beneficial effects**	**Food**
Inulin	IBD, colonic cancer, immune modulation, absorption of minerals, cardiovascular diseases	Low-fat fermented milks, yogurts, dairy desserts, cheeses and ice cream, baked products
Fructo-oligosaccharides	IBD, colonic cancer, immune modulation, absorption of minerals, cardiovascular diseases	Baby food, yogurts, bread, baked products
Galacto-oligosaccharides	IBD, colonic cancer, immune modulation, travellers' diarrhea, antibiotic-associated diarrhea	Yogurts, fruit juices

Some edible plants contain useful dietary components like oligofructose and inulin. They are dietary fibers, which are non-digestible oligosaccharides. Their functional effects are directed toward the gastrointestinal physiology, immunological system, minerals' bioavailability, lipid metabolism, colonic carcinogenesis, and the bacteria in the colon that ferment them and use them as selective fertilizers [21]. Medical science is progressing due to trends in dietary nutrition and personalization, which highlight the need for systemic innovations and adaptation [22]. Prebiotic application may then help to restore the diversity and activity of the gut flora. New information from a community-wide microbiome investigation showed that prebiotics have a wider impact on the gut microbiota than was previously thought, contrary to the previously recognized definition of prebiotics, which only included a small number of bacterial species in the prebiotic activity. The present meaning has to be updated in light of these discoveries. Further research using germ-free animal illness models will be necessary to determine whether prebiotics also have immunomodulatory effects through microbiota-independent mechanisms [23].

Probiotic: Live Microbes for Gut Health

The word "probiotic" was initially used by Lilly and Stillwell in 1965 to refer to compounds that an organism secretes that aid in the growth of another [24]. The Greek word "pro bios," which means "for life," is where the term "probiotic" originates. Cheese and fermented milk have been a part of human history from the beginning of life. The Greeks and Romans were fully aware of them and advised against consuming them, especially for young people and those recovering from illness [25]. Administered to enhance microbial balance, especially in the gastrointestinal system, probiotics are live, non-pathogenic microorganisms. They are governed as dietary supplements and foods and comprise lactic acid bacteria, such as *Lactobacillus* and *Bifidobacterium* species, or *Saccharomyces boulardii* yeast [26]. The ability of *Lactobacillus GG* to cure or prevent diarrheal illness, prevent rotavirus-induced diarrhea, reduce allergic reactions to milk, prevent alcohol-induced liver disease, prevent colon cancer, and act as an adjuvant for vaccinations are all shown [27]. Probiotics make up the majority and continue to expand in size of the global functional food market, which is expected to be worth over US$75 billion. Probiotics account for over 65% of this market [28]. Probiotic treatment has sparked interest in the study of allergy, inflammatory, and infectious diseases in humans. Childhood acute infectious diarrhea is the most well-documented illness that modifies the gut flora. To prevent aberrant immune responses linked to inflammatory and allergy disorders, current probiotic research attempts to offer a safe but enough bacterial stimulation [29]. Medical practitioners are increasingly recommending probiotics as efficacious therapeutic interventions as a popular method to control immunological and digestive health. Since its introduction at the beginning of the 20th century, probiotic science has made significant strides, particularly in the last 20 years. A widely accepted definition has been established by researchers, who have also started to comprehend many of the mechanisms of action, identified traits critical to probiotic function, and gathered clinical data confirming the health advantages and product quality of probiotics [30]. To choose and create probiotics rationally, it is still necessary to have a foundation of knowledge regarding the genetics and physiology of candidate strains that are pertinent to their roles in the gut, functional activities, and interactions with other resident bacteria. So, to clearly describe their contributions to the gut microbiota and finally pinpoint the genotypes that govern any special and advantageous qualities, genetic characterization of probiotic cultures is important. That makes strain selection and differentiation possible, based on a potential probiotic's genetic complement and programming [31].

Table 2 The primary probiotic species used on a commercial basis in food and medication [32]

Species	**Strains**
Lactobacillus	*acidophilus, johnsonii, plantarum, rhamnosus, delbruecki, reuteri, fermentum*
Brevis	*lactis, cellobiosus, paracasei, helveticus*
Bifidobacterium	*lactis, pseudocatenulatus, catenulatus, bifidus, infantis, longum, thermophilus, adolescentis*
Streptococcus	*intermedius, salivarius, cremoris, lactis*
Aspergillus	*niger, oryzae*
Leuconostoc	*mesenteroides*
Pediococcus	*acidilactici*
Enterococcus	*cesium*
Lactococcus	*lactis*
Saccharomyces	*boulardii*
Propionibacterium	*freudenreichii*

Research has indicated that encasing cultures in diverse carriers, such as complex (prebiotic) polysaccharides and milk proteins, can yield notable protection for the cultures. The resulting products often have higher probiotic viability and, because they contain both prebiotics and probiotics, can be considered "synbiotics" (Roberfroid 1998). Overall culture viability can also be significantly impacted by the physiological condition of the probiotic cultures that are being introduced to a product [33].

Synbiotic: The Synergy of Prebiotics and Probiotics

Gibson and Roberfroid (1995) defined synbiotics as "mixtures of probiotics and prebiotics that beneficially affect the host by improving the survival and implantation of live microbial dietary supplements in the gastrointestinal tract, by selectively stimulating the growth and/or by activating the metabolism of one or a limited number of health-promoting bacteria, thus improving host welfare." Synbiotics were first introduced alongside prebiotics [34]. In the last ten years, there has been a surge in research on the synbiotics a combination of pro- and prebiotics that improve both human and animal health. Numerous clinical trials have evaluated a wide variety of synbiotic formulations [35]. Thus far, non-digestible oligosaccharides and fructans of which chicory fructans are a key component have been identified as prebiotics. Chicory fructans are natural food ingredients that are classed as β (2-1) fructo-oligosaccharides. They have such a good impact on a variety of physiological processes that they are currently or may someday be categorized as functional food ingredients, allowing claims of functional effects or decreased risk of disease to be validated. They belong to the prebiotic group and have been demonstrated to enhance the amount of bifidobacteria in the feces of humans. They are bifidogenic at a dose of 2·75 g/d as part of a synbiotic-type product, and the effect lasts for at least 7 weeks [36]. The gastrointestinal tract is home to over 70% of the immune system. Saliva and gastrointestinal secretions are crucial for proper operation, as are the bacteria (probiotics) and provided fibers (prebiotics). Numerous molecular pathways have been demonstrated by probiotic microorganisms to impact the immune system. Fermentation-derived pre-, pro-, and synbiotics provide defence and treatment for a range of acute and endemic illnesses [37]. Research conducted on animals suggests that the gut microbiota's composition could have a role in the development of insulin resistance into type 2 diabetes. By favorably altering the makeup of the gut microbial population, lowering intestinal endotoxin concentrations, and reducing energy harvest, probiotics and/or prebiotics may be a promising strategy to improve insulin sensitivity [38]. Typically, synbiotic products have a blend of *Bifidobacterium*, *Lactobacillus*, or *Streptococcus* species along with a carbon substrate (such as lactose, lactulose, or inulin) that facilitates the growth of these microorganisms. Food firms have benefited from the past usage of probiotics in food and drink items as well as marketing geared toward digestive health. businesses like General Mills, Danone, and Nestlé hold the lion's share of the probiotic market share. These businesses are actively investing in research and development to broaden their range of probiotics and prebiotics [39]. Total antioxidant capacity (TAC) and malondialdehyde (MDA) levels in human breast milk were found to be affected by synbiotic supplementation. Breastmilk TAC in the supplemented group increased considerably ($p<0.039$) from 0.312±0.16 to 0.481±0.2 mmol/L, while in the placebo group, it declined ($p>0.13$) from 0.317±0.18 to 0.255±0.13 mmol/L. The MDA level in the supplemented group declined marginally from 1.62±0.69 to 1.6±0.95 μmol/L, however after the study period (p<0.001), it increased dramatically in the placebo group from 1.71±0.86 to 2.16±0.277 μmol/L. Moreover, during the study period, there were no appreciable differences in the mother's intake of zinc, selenium, vitamins A, E, and C. Furthermore, a significant association between the weight for the infants' age Z-score and the amounts of TAC and MDA in their breastmilk was not seen [40].

Table 3 Tarhana, or fermented cereal, a Turkish delicacy: ingredients

Ingredients	% w/w
Whole wheat flour	35
Synbiotic yoghurt	25
Fresh onions	12
Fresh tomato	10
Fresh red pepper	6
Green pepper	4
Baker’s yeast	4
Salt	2
Dill powder	1
Sweet marjoram	1

Tarhana is a good source of minerals, B vitamins, organic acids, and free amino acids. It can also be regarded as a probiotic and functional food with a hypolipidemic impact because it is a byproduct of yeast fermentation and lactic acid bacteria [41].

CONCLUSION

The fields of food microbiology, prebiotics, probiotics, and synbiotics offer profound insights into the intricate relationships between microbial communities and human health. From Pasteur's groundbreaking work in understanding fermentation to the contemporary advancements in predictive food microbiology, the journey has been remarkable. The integration of proteomics in food allergy research and the development of rapid microbiological monitoring technologies underscore the ongoing efforts to ensure food safety and quality.

Prebiotics, with their ability to nourish beneficial gut bacteria, have emerged as promising agents for promoting gastrointestinal health and mitigating various diseases. Similarly, probiotics, with their live microbial cultures, continue to garner attention for their therapeutic potential in addressing immune, digestive, and inflammatory disorders. The synergistic effects of synbiotics, combining prebiotics and probiotics, further expand the spectrum of applications, offering holistic approaches to improving overall well-being.

Research into the composition and function of gut microbiota, coupled with advancements in genetic characterization and strain selection, holds immense promise for the future of personalized nutrition and targeted therapies. As we continue to unravel the complexities of microbial ecology and its implications for human health, interdisciplinary collaborations, and technological innovations will undoubtedly drive further progress in this dynamic field. Ultimately, the integration of microbiological insights into food production, processing, and consumption holds the key to enhancing both food safety and public health on a global scale.

CONFLICT OF INTEREST: None

AUTHOR CONTRIBUTION: All authors contributed equally.

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